PERFORMANCE ANALYSIS OF A FRANCIS TURBINE USING COMPUTATIONAL FLUID DYNAMICS CODE

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Universiti Malaysia Sarawak

1999

BORANG PENYERAHAN TESIS

Judul: PERFORMANCE ANALYSIS OF A FRANCIS TURBINE USING COMPUTATIONAL FLUID DYNAMICS CODE

SESI PENGAJIAN 1998/99

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30/4/99.

Submission Date

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PERFORMANCE ANALYSIS OF A FRANCIS TURBINE USING COMPUTATIONAL FLUID DYNAMICS CODE

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Thesis Submitted To

Faculty of Engineering, University Malaysia Sarawak

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Undergraduate Degree with Honours in

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PENGHARGAAN

Penghargaan ditujukan kepada Encik Andrew Rigit dan Encik Nazeri Abdul Rahman di atas bimbingan mereka sepanjang tempoh penulisan tesis ini. Saya juga ingin merakamkan penghargaan kepada Dr. Jeremy Wu dan Encik Prakash yang banyak membantu terutama diatas cadangan mereka didalam menggunakan perisian Phoenics. Akhir sekali, saya ingin mengucapkan terima kasih kepada kedua ibu bapa saya dan tunang saya, Cik Juliana Abdul Rahman diatas galakan dan sokongan mereka.

ACKNOWLEDGEMENTS

Acknowledgements are due to Mr. Andrew Rigit and Mr. Nazeri Abdul Rahman for their supervision during the writing of this thesis. I also wish to express my sincere appreciation to Dr. Jeremy Wu and Mr. Prakash, who have been helpful, especially for their suggestions in using the Phoenics software. Finally, I would like to thank my parents and fiancee, Miss Juliana Abdul Rahman for their encouragement and support.

ABSTRAK

Stesen janakuasa hidroelektrik menjana elektrik daripada sumber kuasa hidro. Prestasi sebuah stesen janakuasa hidro banyak bergantung kepada faktor-faktor kedudukan tapak hidro seperti turus, tekanan dan kadar alir air. Walau bagaimanapun, prestasi sebuah stesen janakuasa hidro tidak boleh dititikberatkan hanya kepada parameter-parameter ini tanpa mengambilkira faktor-faktor lain seperti sudut halaju mutlak di bahagian masuk dan keluar dan juga kecekapan turbin. Tesis ini dibuat untuk menjalankan kajian terhadap kecekapan sebuah turbin Francis dengan menggunakan kaedah pengkomputan dinamik bendalir. Salah satu daripada perisian pengkomputan dinamik bendalir iaitu Phoenics telah digunakan untuk meramal nilai halaju keluar aliran air yang meninggalkan pendesak dan seterusnya mengkaji kesan mengubah sudut bilah pandu keatas kecekapan turbin. Hasil kajian menunjukkan bahawa kecekapan turbin Francis dapat ditingkatkan dengan mengubah sudut bilah pandu melalui penambahan sudut daripada sudut asal.

ABSTRACT

Hydroelectric power plants generate electricity from hydropower. The performance of a hydropower plant depends greatly on the factors of a hydro location site such as the available head, pressure and water flow rate. However, the performance of a hydropower plant should not only emphasis on these parameters without taking into considerations other essential factors such as inlet and outlet absolute flow angle and the turbine efficiency. This thesis will carry out a study using computational fluid dynamics method to investigate the efficiency of a Francis turbine. A computational fluid dynamics code, Phoenics have been used to predict the outlet flow velocity of water leaving the runner and determine the effect of changing guide vane angle on turbine efficiency. The results of the study indicated that the efficiency of a Francis turbine could be improved by increasing the guide vane angle from its initial orientation.

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NOTATION

A	:	Cross sectional area (m^2)
b	:	Blade passage width (m)
B	:	Blockage factor
d	:	Diameter (m)
E	:	Energy supplied (kJ)
g	:	Gravitational acceleration (m/s^2)
H	:	Head (m)
m	:	Mass flow rate (kg/s)
N	:	Rotational speed (rpm)
P	:	Power output (kW)
q	:	Heat transfer (kJ/kg)
Q	:	Volume flow rate (m^3/s)
r	:	Radius (m)
T	:	Torque (Nm)
V	:	Velocity (m^3/s)
w	:	Work per unit mass (kJ/kg)
W	:	Work done (kJ)

Greek symbols

α	:	Absolute flow angle (degrees)
β	:	Relative flow angle (degrees)
η	:	Efficiency
ω	:	Angular velocity (rad/s)

π	:	Pi, dimensionless parameter
ρ		Density of water (kg/m^3)

Subscripts

1	:	Runner outlet conditions
2		Runner inlet conditions
f	:	Reference to flow velocity
H	:	Hydraulic
O	:	Overall
r	:	Reference to relative velocity
s		Reference to specific speed
w	:	Reference to swirl velocity

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Introduction

With the coming of the new millenium, there will be an estimated growth of world population from 5.4 to 8 billion people (1). This estimation in real life represents the need for sources, one of which is energy namely electricity. This will be an obvious need for increasing demand for electricity for the purpose of economic and social development.

Energy is an essential need for modern living. Supply of electricity for domestic purposes of penetration of electrical appliances consume a large portion of electricity compared to other needs for public facilities which are essential for development in industrial and transportation sectors

With the growth in millions and the growing trends of urbanization, mega cities and metropolitans are built at rapid rate. This trends leads to a high demand of energy for light up buildings, houses, roads and other uses of electrical power. Not the least of important in energy consumption activities are heavy industries, which include steel, coal, cements, and other industries, which include chemicals and etceteras.

The growths of cities are parallel with the growing needs for the transportation sector. Widely used modes of transportation such as electric trains, coupled with the need to build airports and railway stations also means that there will never be a shortage of demand for energy supply.

However, the most important contribution of the high energy demands comes from the building of infrastructure. Such as transportation, the building of infrastructure is an essential part of modern living. Roads, hospitals, ports, factories are built to ensure comfortable living of the population. These obviously need electricity to be able to serve their purposes.

1.2 Global Energy Demand

After a slow growth in five years, the world energy demand achieved the highest increment of about 2.5 percent in 1995, the highest since 1989. The increase in energy demand worldwide was due to the economic recovery of non-Organization for Economic Cooperation and Development (OECD) countries in the world. The growth of energy demand for non-OECD countries for 1995 was 3.2 percent while the energy growth for OECD parts of the world was 1.9 percent (2).

The contribution to the growth of non-OECD came from the growth of energy demand in non-OECD Europe, 4.4 percent in 1995 but slowed down by 3.3 percent in the former Soviet Union. Except for non-OECD regions in Africa, other non-OECD countries in the world shown a growth of energy demand in 1995 (2).

For the year 1995, the increase in energy demand was 7 percent for Asia, 5 percent for Latin America, 3.3 percent for Middle East and 3 percent for Africa after a 7 percent growth peak in the previous year in the Africa regions (2).

The world energy demand is currently increasing at a rate of 2 percent per annum with the estimated worldwide capacity is 650,000 MW (3). Due to the increasing needs for energy worldwide, the world energy demand will rise by 65 percent to 95 percent by the year 2020 (1). The world energy demand growth from 1996 to 2010 is forecasted as in Figure 1.1 (4).

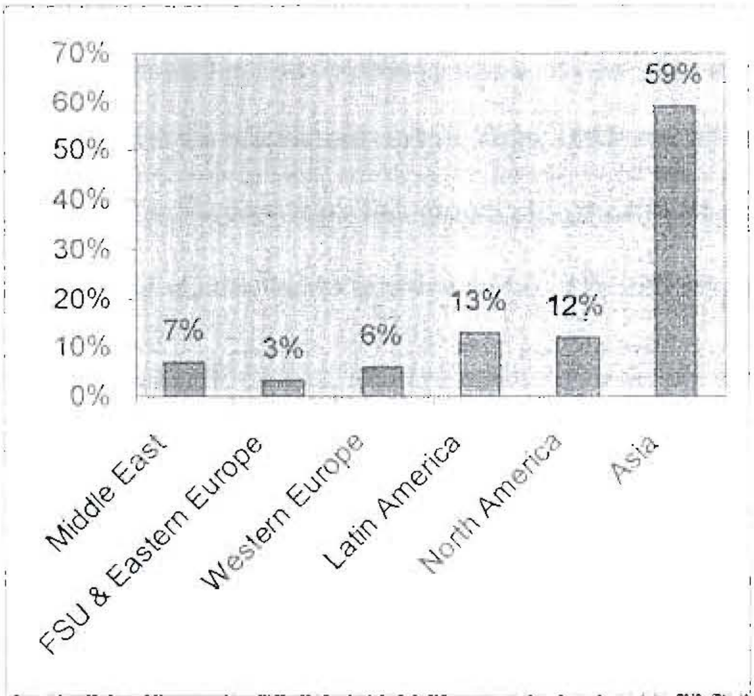

Figure 1.1 World Energy Demand Growth

Source: Ecotech

1.2.1 Energy Demand in Malaysia

As for Malaysia, the stable economic growth since the last decade has led to an increase in demand at a rate of 10 percent per annum. The increase in energy demand from 1996 to 2000 is expected to reach 10,448 MW and 16,389 MW by the year 2005, which inclusive of a 35 percent reserve margin to ensure security of supply (5). The energy demand forecast is based on Gross Domestic Product (GDP) growth of 8 percent a year and the amount of energy consumed in the previous years. For an example, the country has consumed a total of 31,874 GWh of energy in 1994. Out of this, the industrial sector took up 16,760 GWh, commercial sector consumed 9,064 GWh while the domestic sector consumed 5,805 GWh and the remaining 245 GWh was used for public lighting (5).

1.2.2 Energy Demand in Sarawak

There is no exception for Sarawak as 11,942 GWH of energy used in 1996 is forecasted to grow at an average of 12.3 percent per annum from 1997 to 2000 and 7.2 percent in between 2001 to 2006 (6). To cope with this growth, the maximum energy demand will increase every year and it is anticipated to reach 1,009 MW in 2006 as shown in Figure 1.2 (6).

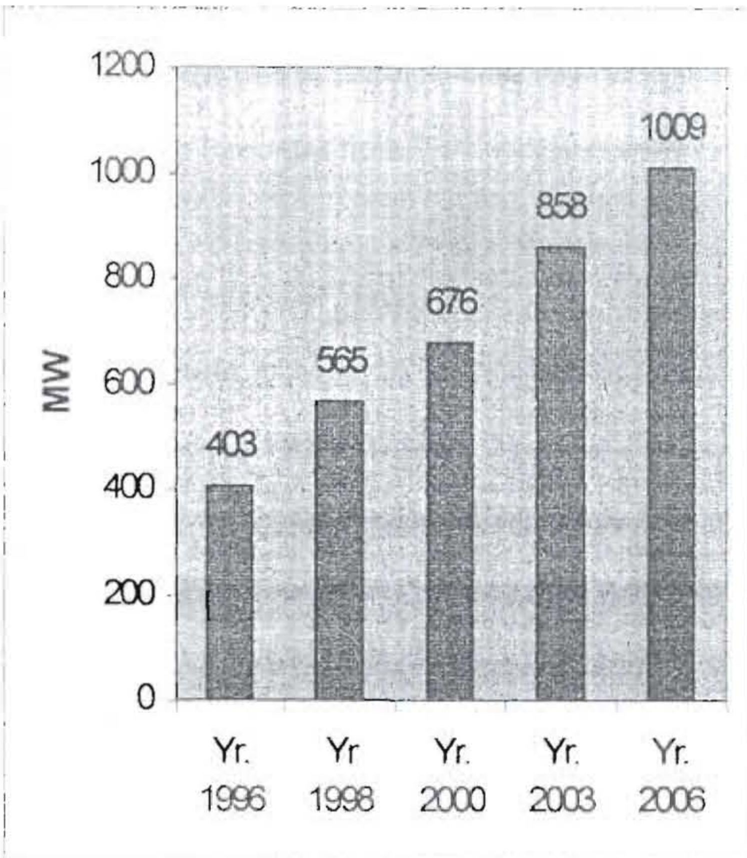

Figure 1.2 Maximum Energy Demand in Sarawak

Source: Sarawak Electricity Supply Corporation

1.3 Power Generation Scenario

Two types of energy used in power generation to produce electricity are non-renewable and renewable energy. Non-renewable energy resources such as coal, oil and natural gas took millions of years to form and are quickly becoming scarce and depleted. Renewable energy uses plentiful or infinite resources that may not be depleted such as hydro energy, solar energy, wind power and geothermal energy.

In order to reduce dependency on one type of energy source and to minimize the pollution especially from the emission of carbon dioxide from fossil fuel burning, the power generation worldwide use both type of non-renewable and renewable energy. The world power generation scenario as forecasted from 1996 to 2010 is shown in Figure 1.3 (4).

1.3.1 Power Generation Scenario in Malaysia

The power generation scenario in Malaysia is based on Malaysia's four-fuel policy, which was introduced after the global oil crisis in the 1970s. The policy emphasizes the energy mix of gas, oil, coal and hydro instead on depending only on oil for electricity power generation. The energy mix for power generation in Peninsula Malaysia is shown in Table 1.1 (7). For Sarawak, the energy mix is shown as Table 1.2 (6).

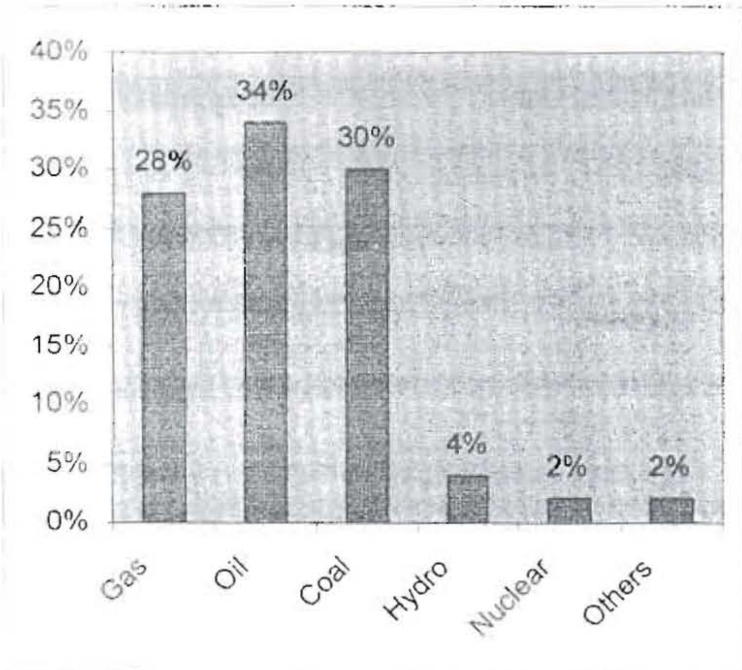

Figure 1.3 World Power Generation Scenario

Source: Ecotech

Types of Power Generation	Installed Capacity (MW)
Diesel	10
Gas Turbine	258
Coal	600
Hydro	1222.5
Combined Cycle	1419.5
Oil & Gas	1739

Table 1.1 Power Generation in Peninsula Malaysia

Source: Tenaga Nasional Berhad

Types of Power Generation	Installed Capacity (MW)
Coal	100
Hydro	110.5
Oil	240.8
Gas	241.8

Table 1.2 Power Generation in Sarawak

Source: Sarawak Electricity Supply Corporation

1.4 Hydropower

Being a reliable and efficient source of power in the world, hydropower is the largest renewable energy in the world and currently provides one-fifth of the world's electricity. By utilizing flowing rivers, high changes of elevation and adequate amounts of water, most countries in the world chose to produce electricity through hydropower facilities. For example, in the Pacific Northwest of United States, there are 58 hydroelectric dams, which contribute about 63 percent of the total power generated in that area. Brazil is producing 75 percent of its electricity through hydropower plants and currently constructing the world's largest dam, Itiapu dam (8).

The potential hydropower worldwide is about 15 trillion kWh as estimated by the UN (United Nation) with 13 percent has been developed and most of the potential hydropower sites are in former Soviet Union, South Asia and South America (3). More than 100 countries are developing small hydropower plants worldwide adding to the use of hydropower as an alternative renewable energy resource.

1.4.1 Hydropower in Malaysia

Hydropower provides about 9.7 percent of Malaysia's energy needs (9). This percentage will increase to 19.7 percent of the country's energy mix with the completion of the biggest hydropower plant in Bakun with its maximum power generation capacity of 2,400 MW begins its operation in few more years. Table 1.3 (9) shows hydropower plants in Malaysia.

Hydropower Plants	Installed Capacity (MW)
Chenderoh Power Station, Perak	40
Tenom Pangi, Sabah	66
Sungai Piah, Perak	70
Berisa, Perak	72
Sultan Yusof Power Station, Pahang	100
Batang Ai, Sarawak	108
Kenering, Perak	120
Sultan Idris II Power Station, Perak	150
Temengor, Perak	348
Kenyir, Terengganu	400
Pergau, Kelantan	600

Table 1.3 Hydropower Plants in Malaysia

Source: Malaysia Forestry Department

1.5 Objectives

This project will focus on the flow between the guide vanes and a runner of a Francis turbine. The study of the flow using a computer software package is then used for improving the performance of the Francis turbine. The overall objectives of this project are to achieve the followings.

1. To understand the theory of hydraulic turbine in hydropower plant.
2. To develop the general equations from the fundamental principles of fluid flow.
3. To study the use of PHOENICS as one of the CFD software packages.
4. To study the flow between the guide vanes and runner in Francis turbine as simulated by PHOENICS.
5. To determine the effects of changing guide vanes orientation on the turbine efficiency.
6. To recommend further works of the project.